THE MEASUREMENT OF FAULTS.

According to the definition given by Dana, "faults are displacements along fractures." Whenever the rocks of the earth's crust are subjected to strain, fractures take place in them as in any other body under similar conditions, and the different parts of the rock tend to move past one another along the fracture-planes, seeking to obtain relief from the strain and to accommodate themselves to new conditions. In this movement one part of the fractured rock-mass may move upon the other in any direction, up, down, sidewise or obliquely, according to the conditions, which are different in each instance. There is, so far as I know, no law governing the direction of movement in faults which is of any use in geological diagnosis. Naturally, when there is any preëxisting plane of weakness of the rock which is subjected to strain the movement takes place by preference along this plane; and, hence, in sedimentary beds, it is probable that movements along the stratification planes constitute the commonest variety of faults. Inasmuch, however, as the beds in disturbed districts lie in every conceivable position, the probability just stated does not give any clew to the average attitude of faults.

The movement in faults can be completely ascertained only by the aid of independent and accidental phenomena. In homogeneous rock-masses (leaving out of consideration fault scarps, fault gulches, and other topographic phenomena, and treating the faulted mass as a solid without boundaries), the amount of movement cannot be ascertained or even approximately estimated; although the *existence* of a fault can be determined by the records left on the slipping surface or surfaces in the shape of ground-up rock or fault-breccia, in polished and striated rock faces, and so on. It is certain, however, that the amount of friction as displayed by trituration and polishing is not neces-

sarily proportionate to the amount of movement, since faults with slight displacement are often accompanied by zones showing profound trituration, while others of far greater movement show to a much less degree the effects of friction. The friction in each case seems to depend upon the angle of the chief stress to the sliding plane, rather than on the amount of movement along this plane. In heterogeneous rocks the amount of movement of a fault can ordinarily be estimated with more or less accuracy, the degree of closeness depending upon the nature of difference in the composition of the rock-mass. In such heterogeneous rocks the amount and direction of a fault movement must be judged by any available phenomenon or phenomena. By far the commonest variations in rock-masses which are constant enough to be reliable as data are sedimentary beds, and therefore the commonest means of measuring a fault movement is the separation of the two parts of an originally continuous stratum. On this account it is easy to fall into the error of considering faults simply as dislocations of strata. In careful geological work, however, such as mining work must necessarily be, it is important to cultivate a more correct conception, and to regard sedimentary beds as phenomena accidentally associated with faulting, whose dislocation must be associated with all other available criteria, each one as valuable as the other, to determine the amount and direction of the total movement or displacement. Any fault, for example, in which the direction of movement is parallel with the plane of sedimentation will not cause any apparent displacement in a sedimentary bed; and this may be the case in faults having any conceivable attitude, since the sedimentary beds themselves may be folded so as to stand in any conceivable attitude with reference to any fixed plane, such as the earth's surface.

When the direction of movement in a fault lies at a slight angle to the plane of sedimentation, the apparent displacement of a stratum resulting from this fault will be only a slight part of the actual fault movement; and it is only when the direction of movement is perpendicular to the plane of sedimentation that

the separation of the parts of the faulted stratum is an accurate measurement of the movement. Theoretically speaking, the chances are infinitely against any such coincidence, and in actual practice it is rare that the movement may be even approximately estimated in this way. In mining geology it has been found that the most valuable criteria for measuring faults are, besides sedimentary beds, igneous bodies, such as dikes ; bodies of ore ; striæ on the fault plane, showing the direction of movement ; and the composition of the fault breccia, which may show, in some degree, the amount of movement. By taking several of these criteria together it is often possible to actually ascertain the movement of a fault.

It is sometimes possible to find out the amount and direction of movement immediately ; but more often it must be indirectly calculated, and to do this it is important to have clearly in mind the nature and value of some of the principal functions of a fault movement, and to have specific terms by which to designate them. The terms already in use are of a rather vague and general character, resulting from the usual conception of a fault as a dislocation of strata ; the four generally employed are *displacement*, *throw*, *heave*, and *offset*. The words *displacement* and *throw* are used interchangeably, and commonly refer to the separation of beds by a fault as seen in a vertical section. Each of these terms is used by some to indicate the distance along the fault plane between the broken ends of the bed as seen in the section, and sometimes the perpendicular distance between the parts of such beds, projected, if necessary. There is no agreement, however, which definitely assigns the terms to separate measurements, and, indeed, it is very common for a writer to use the terms interchangeably for one or the other function. *Heave* and *offset* are also used interchangeably, and are usually held to signify the perpendicular distance measured on a horizontal plane, such as the earth's surface, between portions, projected, if necessary, of a bed separated by a fault.

In mining work it is generally necessary to clearly differentiate the different functions of a fault movement, and I have

adopted the following terms descriptive of the most important of these; these terms include nothing very novel in the way of nomenclature, but are intended simply to affix definite names to definite things.

Dislocation and *displacement* are general terms, applicable to any part or the whole of a fault movement. Each of the functions defined below, and to which specific names are given, may be called simply a dislocation or displacement.

Total displacement is the distance which two points originally adjacent are separated by the fault movement; the line connecting these two points lies in the fault plane in all straight faults. It is occasionally possible to determine the total displacement directly by such criteria as the separation of the parts of an ore body, the intersection of a given dike with a given stratum when found on both sides of the fault, and in other ways; but ordinarily it can only be calculated or approximately estimated from some of its more easily measured functions.

The *lateral separation* is the perpendicular or shortest distance between the two parts of any continuous zonal body (such as a sedimentary bed), which has been separated by a fault, the distance being measured along the fault plane. The lateral separation may be measured in a vertical, horizontal, or oblique line, according to the attitude of the bodies between which it is measured, and in any fault it may vary from zero to the total displacement. In the case of dikes cutting sedimentary beds, of marked unconformity, of abrupt folds, and so on, it may be possible to measure two or more lateral separations in a single fault. In this case, and in a number of others which are possible, the total displacement may often be calculated from the lateral separation, since the latter is always the side of a right triangle of which the former is the hypotenuse.

The *perpendicular separation* is the perpendicular distance between corresponding planes in the two parts of any single body available as criterion (such as a sedimentary bed), when this body has been separated by a fault, the planes on each side of the fault being projected for the purpose of measuring, if neces-

sary. The perpendicular separation thus has a certain relation to the lateral separation; for it constitutes a side of a right triangle, the hypotenuse of which is the lateral separation, except in the possible case where the perpendicular and lateral separations coincide.

This mathematical relation makes it often possible to estimate the lateral separation from the perpendicular separation, and from the latter the total displacement. Of these three functions, the perpendicular separation is most easy of measurement, and its value may vary from zero to the full amount of lateral separation. The lateral separation is easier to ascertain than the total displacement, and its value may vary from zero to the total displacement.

The measurements which have been defined have no constant direction, since they refer to fault movements which are capable of infinite variation. In general geological work, however, it is often only possible to measure fault movements along certain arbitrary planes. The most valuable of these planes, are the earth's surface, which may be considered a horizontal plane, and vertical sections, into which available data are put, with the gaps in the chain of information often theoretically filled out. In such cases, where some dislocation is evident, but the information is so meager that it is not possible to know the fault so accurately as to estimate even approximately its total displacement or lateral or perpendicular separation, it is necessary to employ specific terms to designate the known or estimated dislocations, although the relations of these dislocations to the total displacement may be unknown. For this purpose the terms *offset*, *throw* and *vertical separation* may be used. The terms *throw* and *vertical separation* are applied to the dislocations of a fault as seen in a vertical section; the term *offset* to the dislocation as seen in a horizontal section, such as the earth's surface may be considered to be.

A *throw* may be defined as the distance between the two parts of any body available as a criterion (such as a sedimentary bed), when these parts have been separated by a fault, the dis-

tance being measured along the fault plane as shown in a vertical section.

The *vertical separation* is the perpendicular distance between the intersection of the two parts of any faulted body available as a criterion (such as a sedimentary bed), with the plane of a vertical section, the lines of intersection being projected if necessary for the purpose of measurement. In perpendicular faults the vertical separation is identical with the throw; in all others it is less than the throw, but sustains a certain relationship to it, being one side of a right triangle of which the throw is the hypotenuse. Thus the vertical separation may vary from zero to the full amount of the throw. The throw is always a part of the total displacement, although with no definite relationship to it, and varies from zero to the full total displacement.

The term *offset* may be used to designate the perpendicular distance between the intersections of corresponding plane in the two parts of any faulted body available as a criterion, such as a sedimentary bed, with a horizontal planes such as the earth's surface may be considered to be; the planes being projected for the purpose of measuring, if necessary. Like the throw, the heave or offset is a part of the total displacement, but has no definite relationship to it.

To sum up, there are six terms proposed to designate the different parts of a fault movement, each term applying to a measurement which varies in accuracy and proximity to the total displacement in proportion to the available amount of information. For general outline work where accurate data are not obtainable, the terms *throw* and *vertical separation*, referring to the measurements of a fault at its intersection with a vertical plane, and the term *offset*, indicating a measurement of a fault at its intersection with a horizontal plane, are adopted. The throw and offset are parts of the actual fault movement, but of unknown value, while the vertical displacement sustains a certain relationship to the throw. Where more complete data are obtainable, the terms *total displacement*, *lateral separation*, and *perpendicular separation* are adopted. The perpendicular separation sustains a certain rela-

tionship to the lateral separation, as the lateral separation does to the total displacement.

The terms which have been adopted above have purposely been made as few as is consistent with the plan of furnishing a scheme for complete fault-analysis. The number might be increased indefinitely; yet ordinarily this is undesirable, for most other fault measurements are simple mathematical functions of the terms above adopted, and can be easily reduced to one of these; and the great multiplication of terms leads to confusion in a study which is at best not too simple. In specific instances, however, it may be desirable to increase the number of terms, and to give separate names to other fault measurements.

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